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A DUAL POLARIZED MICROSTRIP ANTENNA ARRAY WITH PORT DECOUPLING FOR MIMO SYSTEM

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1 Introduction

Utilization of multiport-antennas represents an appropriate way for the mitigation of multi-path fading in wireless communication systems [1], [2]. Furthermore, by using multiport-antennas at both ends (Multiple Input Multiple Output, MIMO) in combination with appropriate spatiotemporal coding techniques, channel capacity can be greatly enhanced [3], [4]. However, to obtain low correlation between the signals from different antenna ports and to prevent gain reduction by cross-talk, large antenna elements spacing is expected, which makes it hard to be realized in small handheld devices [5] or PC-Cards etc.

Recently polarization diversity has drawn much attention because it allows signal separation even with small antenna spacing. Nevertheless, although it is effective, polarization diversity alone does not suffice once the number of antennas exceeds the number of orthogonal polarizations [6]. Hence, for achieving a higher number of degrees of freedom, diversity based on polarization must be combined with diversity based on different angular response in amplitude and/or phase.

In this paper, an approach, which combines a novel array concept with the use of dual polarization, serves as a promising alternative to circumvent this problem. The theory is verified by a compact dual polarized patch antenna array, which consists of four elements and a decoupling network (DN). Furthermore, a new point of view to consider the mutual coupling in highly packed arrays is put forward; that is, with the use of DN, while all four elements are excited, the four ports of the array are still decoupled from each other. In this way, mutual orthogonality between the complex-valued vector radiation patterns of the 4 ports is achieved.

2 Theoretical Analysis

Highly packed arrays suffer from a strong correlation between the radiation patterns associated with their ports and strong mutual coupling results in a significant gain reduction [7]. However, new ports, which are decoupled and uncorrelated, can be obtained by a novel approach with RF decoupling network (DN). In this section, the general theory about DN design will be given.

According to Gupta and Ksienski [8], for multi-port antennas with known port load impedance of Z_L , the element output voltages can be related to open circuit voltages as

$$\mathbf{V}_M = (\mathbf{I}_{MM} + \mathbf{Z}_{MM}/Z_L)^{-1} \cdot \mathbf{V}_{0,M}. \quad (1)$$

Here, vector \mathbf{V}_M is the element output voltages, while $\mathbf{V}_{0,M}$ represents the open circuit voltages at the antenna ports, and \mathbf{Z}_{MM} stands for the symmetric $M \times M$ source impedance matrix $\mathbf{Z}_{MM} = \mathbf{R}_{MM} + j \mathbf{X}_{MM}$, in which non-vanishing off-diagonal elements $Z_{mn} = Z_{nm}$ represent mutual coupling between port m and n . Since matrices \mathbf{R}_{MM} and \mathbf{X}_{MM} are real symmetric matrices, their eigenvalues are real and the corresponding mutually orthogonal eigenvectors exist. Moreover, since adding reactive loading between antenna ports can tune the susceptance matrix while keeping the conductance matrix, we can

always force eigenvectors of \mathbf{R}_{MM} and \mathbf{X}_{MM} to coincide. Thus, we can get

$$\mathbf{Z}_{MM} = \mathbf{U}_{MM} \cdot \mathbf{z}_{MM} \cdot \mathbf{U}_{MM}^T \quad (2)$$

where $\mathbf{U}=(\mathbf{u}_1, \mathbf{u}_2, \dots, \mathbf{u}_M)$ is the unitary matrix composed of the M orthonormal eigenvectors of \mathbf{Z}_{MM} . $\mathbf{z}_{MM}=\text{diag}[z_1, z_2, \dots, z_M]$ is a diagonal matrix, in which each on-diagonal element is defined as mode impedance. Therefore, combining (1) and (2), we have

$$(\mathbf{I}_{MM} + \mathbf{z}_{MM} / \mathbf{Z}_L) \mathbf{U}_{MM}^T \mathbf{V}_M = \mathbf{U}_{MM}^T \mathbf{V}_{0,M} \quad (3)$$

Therefore, we obtained corresponding mode output voltages $\mathbf{v} = \mathbf{U}_{MM}^T \mathbf{V}_M$ and mode open voltages $\mathbf{v}_0 = \mathbf{U}_{MM}^T \mathbf{V}_{0,M}$. To define the mode scattering parameters from the viewpoint of energy, we have:

$$\mathbf{s} = \mathbf{U}_{MM}^T \mathbf{S}_M \quad (4)$$

Here, \mathbf{S}_M is the scattering matrix of original system, while \mathbf{s} represents the scattering matrix of modes. When only one port is fed in an array, different modes are excited simultaneously. Unfortunately, because components in \mathbf{s} are mode-dependent and normally not coincide with each other, cross-correlation and gain reduction between ports arise.

The solution to this problem is provided by a passive network between elements and loads. The so-called decoupling network (DN) provides a mode-specific transformation, such that mode m with mode admittance $y_m = g_m + jb_m$ is at the frequency of operation terminated by $y_{N,m} = y_m^* = g_m - jb_m$. The design of such a DN requires cross-coupling paths between different ports. The new ports are decoupled.

3 Results

Mutual coupling can be reflected by scattering parameters. Both numerical and experimental results are given to verify the feasibility of the theory above. The array considered here consists of four patch antennas. As shown in Figure 1, these four elements are aperture coupled and provide two different polarizations. Figure 2 shows the computed S parameters by IE3D, a commercial EM simulation software. According to the mode definition, mode return losses are given in Figure 3. From the simulation results, it is observed that, with DN, while all the three modes are matched at central frequency (2.45 GHz), these modes have different bandwidth for $\text{VSWR} < 2$. The lowest mode (mode 1) has a bandwidth over 4.1% (from 2.4 GHz to 2.5 GHz); whereas the highest mode (mode 3) has a bandwidth around 1.8% (45 MHz), and the mode 2, in between, around 2.8% (68 MHz).

The whole array is fabricated with top substrate of Duroid 5870 ($\epsilon_r = 2.33$, $t = 3.18\text{mm}$), and the bottom, including DN, of RT 4003 ($\epsilon_r = 3.38$, $t = 0.51\text{mm}$). Figure 4 shows the measured S parameters. Evidently, at between around 2.41 GHz and 2.44 GHz, mutual coupling between the four ports are greatly depressed.

Additionally, the computed radiation pattern by IE3D is given in Figure 5. Figure 5(a) shows the XY-Plane of one-port-fed radiation pattern, where the centerline of the fed element coincide with the X-axis and the whole array is in plane $Z=0$. Theta component in this plane is around -50 dB. Figure 5(b) gives the YZ-Plane of the same pattern. These two figures show high cross polarization discrimination (XPD) at boresight (over 20 dB is observed). Therefore, with this array structure, a polarity diversity system is possible.

4 Conclusion

This paper presents a method to employ diversity both in polarization and angular amplitude/phase response of highly packed arrays. An array with four patches is designed and modified by adding a decoupling network at the feeding. The diameter of the whole array is 65.1 mm and can be further reduced with substrates of a higher dielectric constant, which enables its use in mobiles. Simulation and experimental results indicate that mutual coupling is greatly depressed. Furthermore, with the mode definition in this paper, the scattering parameters to different modes have different bandwidth, which need to be considered in spatiotemporal coding techniques.

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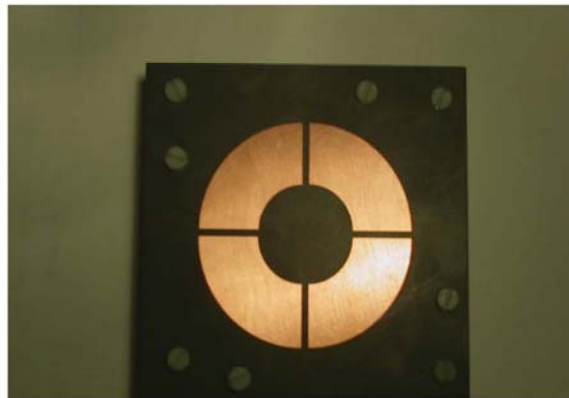


Figure 1. Photograph of the Array

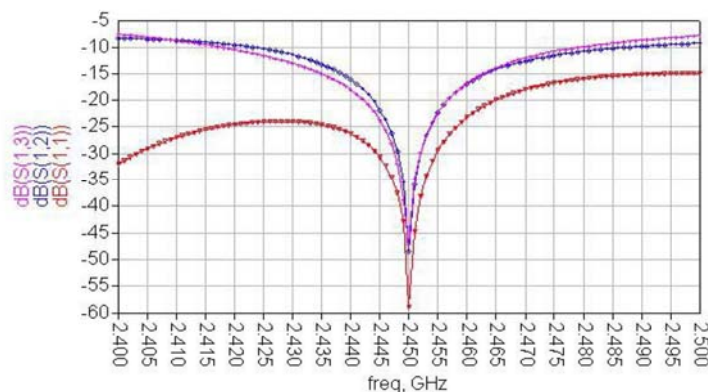


Figure 2. Computed S parameters (Triangle for S11, Circle for S21 and Cross S31)

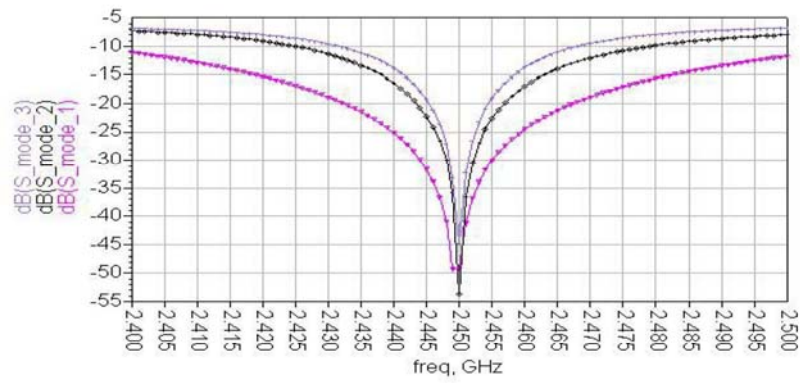


Figure 3. Computed Mode S parameters (Triangle for Mode 1, Circle for Mode 3 and Cross Mode 3)

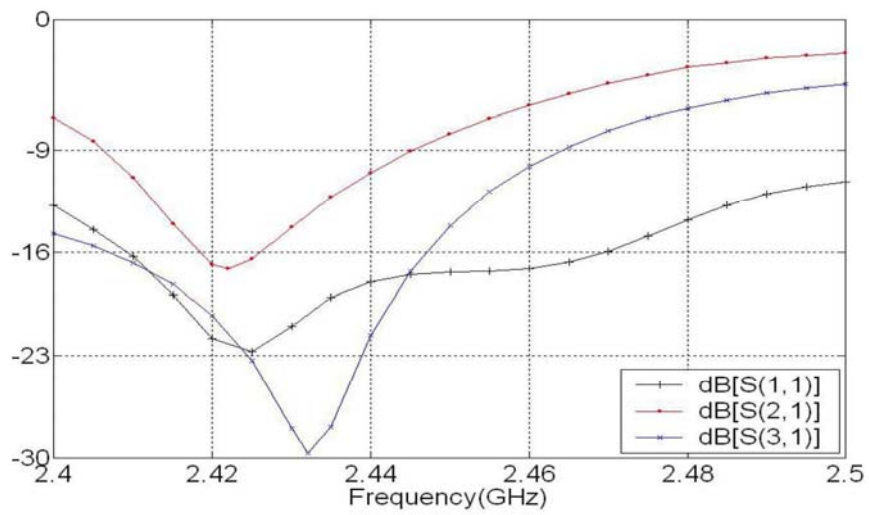


Figure 4. Measured S parameters

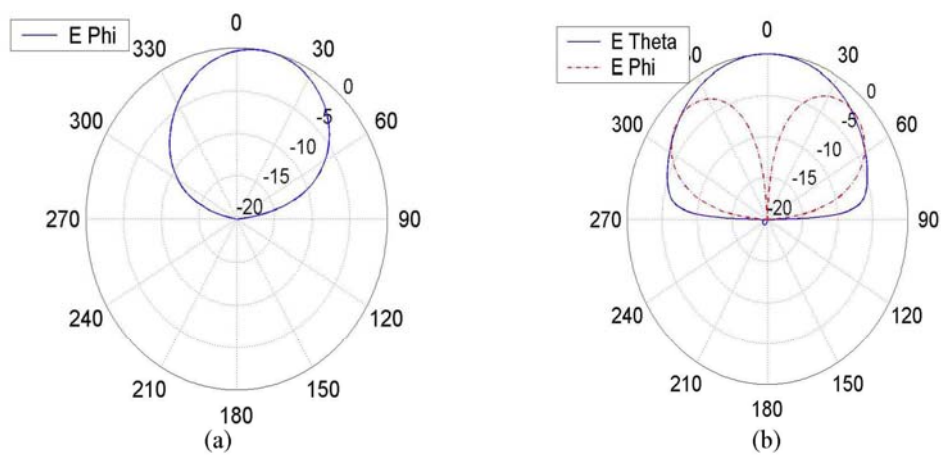


Figure 5. Computed Radiation Pattern (a. E-Phi at XY plane; b. E-Phi and E-Theta at YZ plane)